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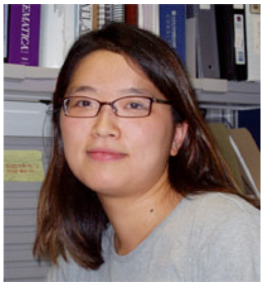
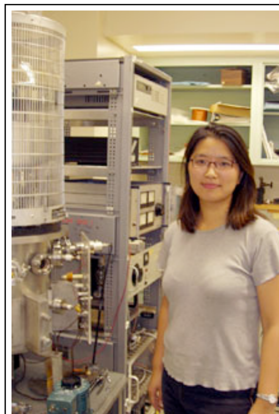
A P-23 Post-doc Wins the Rosen Prize



Dr. Chen-Yu Liu, a post-doctoral appointee in P-23.

On September 4th, the Rosen Prize Committee of the Los Alamos Neutron Science Center (LANSCE) User Group announced the selection of **Dr. Chen-Yu Liu, Princeton University** (now a post-doctoral appointee in P-23, Neutron Science and Technology) as the 19th Louis Rosen Prize recipient for her outstanding Ph.D. thesis, "A Superthermal Ultra-Cold Neutron Source." Dr. Liu is a member of the UCN Team, a collaborative effort between P-23, P-25 (Subatomic Physics), Princeton, North Carolina State, Caltech, Institut Laue-Langevin, University of Kyoto, and the Petersburg Institute for Nuclear Physics. The Rosen Prize, established by the Los Alamos Meson Physics Facility (LAMPF) Users Group, Inc., and now administered by the LANSCE User Group, is awarded to the student with the best thesis based on work done in whole or in large part at LANSCE.



Dr. Liu in her lab; at left is an evaporation chamber—part of her UCN source.

The Louis Rosen Prize

Established in 1983, the Louis Rosen Prize is awarded to the student with the best Masters thesis or Doctoral dissertation based on research performed at LANSCE. The Rosen Prize Committee, a special committee of LANSCE User Group members, judges the submissions. Rosen Prize Committee members are selected by the LANSCE User Group Executive Committee. To be eligible for the prize, the thesis or dissertation must be completed between May 1st and April 30th of the annual cycle. The Rosen Prize committee judges each submission on the thesis or dissertation's originality, the extent of the student's contribution to the research, and its scientific impact.

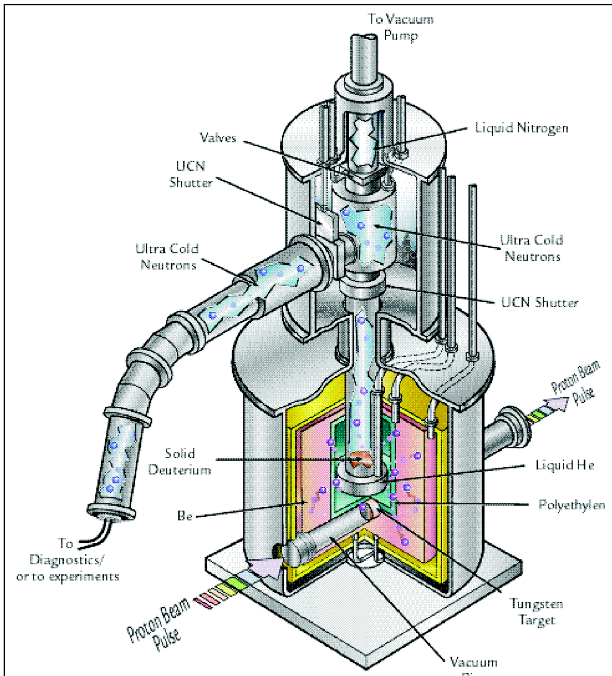


Figure 1. A concept drawing of the prototype solid-deuterium source. The 800-MeV proton beam from the LANSCE accelerator strikes the tungsten target, producing ~18 neutrons for every incident proton. These neutrons are reduced to cold-neutron temperatures by scattering in polyethylene moderators at 77 K and 4 K. They downscatter into the UCN regime as they interact with the solid deuterium.

Dr. Liu will be formally presented with the Louis Rosen Prize, a plaque and a monetary award, during the upcoming LANSCE User Group Meeting, October 19–21. She will also give a technical presentation based on the work done in her dissertation, "A Superthermal Ultra-Cold Neutron Source" (Figure 1). Said Dr. Steve Lamoreaux, Chen-Yu's mentor in P-23, "Chen-Yu's easy and mild-mannered style belies the fact that she was really the best graduate student I have ever worked with. Her theoretical analysis of the upscattering of ultra-cold neutrons from rotationally excited deuterium molecules provided the crucial explanation of the failure of our prototype ultracold neutron (UCN) source to produce the expected density. This problem had some five senior scientists stumped for about two years. Her work was so compelling that I attended her Ph.D. defense at Princeton. Her dissertation was rated 'outstanding,' a rating reserved for one or two Princeton physics Ph.D.s per year. We were really fortunate to attract her to Los Alamos for her post-doctoral studies. Certainly, there hasn't been a dull moment since."

A native of Taiwan, Chen-Yu earned her bachelor’s degree in physics from National Taiwan University. She came to America in 1997 to pursue graduate studies in physics at Princeton University. In addition to her Princeton classes and research, she spent a lot of time here at LANSCE to develop the UCN source, and in the last year she visited Triangle University Nuclear Laboratory where she finished work on a UCN spin flipper. “Princeton offered a great environment for advanced physics study. I was given opportunities to participate in very exciting research. However, it wasn't until I came to Los Alamos that I really learned how to efficiently make use of the available resources and make an experiment possible. Here, one is given the chance to apply the knowledge taught in classrooms and textbooks into real work, and furthermore to learn the hands-on knowledge that could never be taught in classrooms.” Dr. Liu earned her Ph.D. in neutron physics from Princeton in 2002.

After a short time at Old Lyme Art Academy, she returned to the Laboratory as a post-doctoral appointee with P-23. “[As a graduate student], I was fortunate to work with Laboratory Fellows Chris Morris and Steve Lamoreaux, who demonstrated to me how be an independent researcher. From them, I learned to have a broad mind, to embrace creative ideas, to be efficient in putting together resources and troubleshooting problems, and to be courageous in building a working piece of apparatus. I also worked with Tom Bowles and Susan Seestrom, and from them I saw how to build a successful research program and push the project forward. There are brilliant scientists here, from whom I have a lot more to learn, and it is why I came back to work at the Lab.” Her current projects include work on the effort to measure the permanent electric dipole moment of the electron (PDF). She is also pushing forward an experimental project to test solid oxygen as a UCN source. In her graduate work, she performed a theoretical calculation to estimate the potential of using magnon in solid oxygen to create UCNs and is now pursuing this idea experimentally.

A New High-Density UCN Source

Experiments with UCNs can offer an order-of-magnitude improvement in the precise measurement of neutron properties that are sensitive to physics beyond the Standard Model of elementary particle physics. UCNs are isolated neutrons that have been slowed and cooled to the point where their kinetic energy is less than 335 nanoelectron volts, their temperature is less than 4 milliKelvin, and their velocity is less than 8 meters per second (human running speed is ~10 meters per second). Cold neutron scattering on condensed matter, which is sensitive to magnetic structure, provides complimentary information to x-ray scattering.

Dr. Liu’s dissertation describes her research as a part of the UCN Team’s efforts to understand and characterize the performance of cryogenic solids (solid deuterium) as superthermal UCN sources that produce UCN densities much higher than that of previous facilities. Her dissertation presents a novel UCN source using cryogenic solid oxygen that may be a better source than the Team’s current apparatus, which uses solid deuterium. Dr. Liu’s dissertation concludes by presenting an implementation of a UCN spin flipper which will be useful for future experiments that require polarized UCNs. Her experimental tests with this device measured a spin-flip efficiency of ~99.6%.

Ultracold Neutrons: What are they and how are they “made”?

Neutrons are neutral, elementary, subatomic particles that are constituents of all elements’ nuclei, with the exception of hydrogen. Neutrons are unstable and spontaneously undergo beta (□) decay (with a half-life of ~10 minutes). They also can pass through matter with no detectable primary ionization. They interact with matter primarily through collision with other nuclei.

Fast neutrons have a long history in scientific research. Fast neutron radiography is a nondestructive testing method with a variety of industrial applications, including elemental analysis and materials classification, and has the potential for element-sensitive imaging for contraband and explosives detection. Another common use for fast neutrons is in soil-moisture measurements taken with neutron probes. In the past couple of decades, physicists have made increasing use of *slow* neutrons for studying the structure and dynamics of matter on atomic, molecular, and macro-molecular scales.

The UCN Team's efforts (and Dr. Liu's research) to develop a high-density UCN source are a great step in the field of slow-neutron research. UCNs could be characterized as *extremely slow* (remember, they travel at ~8 meters per second). This lower energy level gives physicists more control over how they use the neutrons as probes in experiments and the ability to better control the conditions of their experiments. UCNs can be stored for up to their β-decay lifetime (their half-life is ~10 minutes), which is a relatively long coherence time for measurements. UCN energy is so low that reflective walls can trap them—the probability that a UCN will be absorbed as it bounces off a container wall has been measured to be less than one in 10,000—allowing physicists to create much more precise experiments in traps with well-defined geometry. Because they can be trapped by walls, they can be transported to and stored in areas well shielded from radiation in order to perform very-low-background experiments. Also, in principle, experimentalists can achieve 100% neutron polarization with straightforward magnetic filtering.

The process of "creating" a UCN starts when energetic protons in the LANSCE accelerator strike a tungsten target (Figure 2 illustrates the process described in this and the following two paragraphs). In a process known as spallation, a proton interacts with the nucleus of a tungsten atom in the target. As a result of the collision, many particles, including many neutrons, are ejected from the nucleus (see a spallation movie). From here, *medium-speed* neutrons pass into the UCN-source device and through two moderators: first, one of polyethylene (long chains of CH_2 molecules) at 77 Kelvin and a second, colder one of polyethylene at 4 Kelvin.

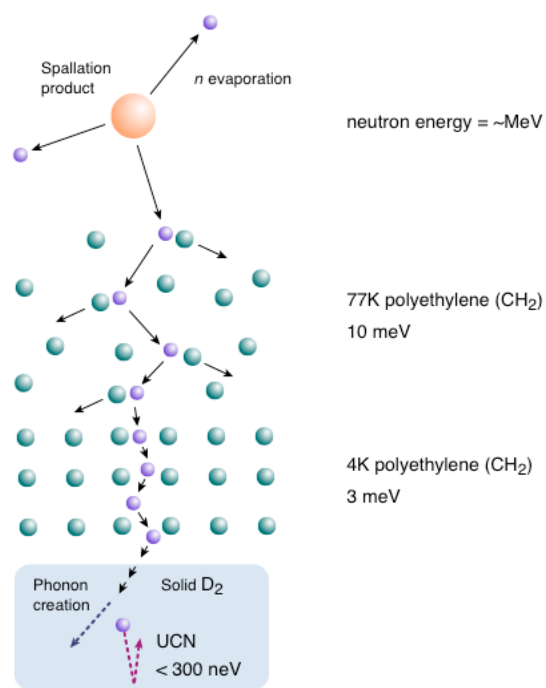


Figure 2. As a neutron collides with hydrogen nuclei in the two moderators (polyethylene at 77 K and 4 K), it loses energy to the "static" particles—cooling and slowing first to 10-meV then 3-meV energies. The neutron's final interaction with solid (frozen) deuterium cools it to the UCN regime (< 335 neV).

In each stage of the moderation, the neutrons collide with the "static" nuclei of the molecules in the moderators. Kinetic theory tells us that these neutrons should lose some kinetic energy to the static nuclei. In this process, the neutron energy is maximally transferred to a target of equal mass, and thus, most of the neutron moderator is hydrogen based. Inside neutron moderators, neutrons experience multiple collisions, lose their energy, and eventually come to the same temperature as the moderator. This is why, in Figure 2, we show the neutrons at 10 meV in the first moderator, and 3 meV in the second.

At this point, the *slow* neutrons pass through and interact with the solid deuterium in the UCN "source." It is during this interaction that the slow neutrons lose enough energy to truly reach the UCN regime (i.e., they reach an energy level of < 335 neV, < 4 mK, and < 8 ms^{-1}).

On the road to perfecting their UCN source (see Figure 1), the UCN Team encountered difficulty in reaching theoretically possible UCN yields. In hydrogen, the spins of the two protons in the H_2 nucleus can either be aligned (total spin = 1) or opposite to each other (total spin = 0). The first state is called ortho-hydrogen, and the second is called para-hydrogen. In deuterium, the situation is slightly more complicated. The nucleus of the deuterium molecule (D_2) is made of two deuterons. Each deuteron nucleus is made of one proton (spin 1/2) and one neutron (spin 1/2), so the total nuclear spin of the deuteron is 1.

The total spin of the two spin-1 deuterons in a D_2 nucleus can be either 0, 1 or 2. The two states with even total spins have a symmetric wavefunction and are called ortho-deuterium. The state with odd total spin has an antisymmetric wavefunction and is called para-deuterium. At low temperatures, ortho-deuterium is the ground state (the state with the lowest possible energy); para-deuterium still holds a finite rotational energy of about 7 meV higher than ortho-deuterium. Both the ortho and para deuterium can create UCNs efficiently with almost the same rate, however, para deuterium can also efficiently "annihilate" a UCN because it can give away its (unquenched) rotational energy to the UCN, and in the process becomes an ortho deuterium. The UCN Team devised a way of filtering out most of the para deuterium molecules within the source allowing them to achieve the highest UCN density (98 ± 5 UCN/cm^3) ever stored!

What do physicists do with UCNs?

With UCNs, researchers can study phenomena such as neutron β-decay, which is purely dominated by the weak interaction—giving the researcher a view of the weak interaction unimpeded by other forces and interactions. Neutron β-decay is the only one of the four basic forces of the universe (electromagnetism, strong interaction, weak interaction, and gravity) that violates parity. Physicists have been trying to measure precisely the parameters of the weak interaction since parity violation was verified in the late 1950s.

UCNs can also be used to measure the permanent electric dipole moment (EDM) of the neutron—to test time-reversal violation symmetry, which corresponds to reversal of motion. Invariance under time implies that whenever a motion is allowed by the laws of physics, the reversal of that motion is also allowed.

In the beginning of the universe, there was energy, not in the form of matter or antimatter. Later, the universe cooled down, and the matter-generating process occurred. Physicists believe that in this process, matter is preferentially generated over antimatter, and this process has to violate CP symmetry (which means time-reversal symmetry is violated, through another theorem stating that CPT has to be conserved). Actually measuring the EDM of the neutron or electron can tell us how much (albeit very small) violation there is.

Finally, the theoretical possibility exists for neutron-antineutron oscillation. Neutron-antineutron oscillation can happen only if a physics process that violates the baryon number conservation (another necessary ingredient to explain the matter-antimatter asymmetry) exists. A high-density UCN source provides us with the means to explore the possibility of neutron-antineutron oscillation.

— by Todd Heinrichs, Physics Division Communications Team